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Changeability by a modular design of production systems – consideration of technology, organization and staff

Horst Meier[a], Stefan Schröder[a]*, Niklas Kreggenfeld[a]

[a] *Chair of Production Systems, Ruhr-University Bochum, Universitätsstraße 150, 44801 Bochum, Germany*

* Corresponding author. Tel.: +49-234-32-27096; fax: +49-234-32-07096. *E-mail address*: Schroeder@lps.rub.de.

Abstract

The steadily alternating and unpredictable requirements for industrial companies implicate the challenge to enhance production systems. As a consequence, the need for action leads to a paradigm shift in production. A transformation from a flexible production to a changeable company occurs. In this context, changeability will be decisive for the desired success. Production systems are used for the purpose of manufacturing products and are attributed to socio-technical systems. A production system is a unit used to realize the production and can include a single machine as well as a complete production area or the whole factory. The staff is also part of production systems and does not only assume organizational responsibilities but also technical tasks. Many already known drivers of change, e.g. new innovations in technologies, have an impact on these socio-technical systems. One chance to react to changing requirements is to apply the principle of modularization. Conventionally, modularization is considered in a technical context. The consideration of staff and organization is disregarded. This article introduces a new approach to design changeable production systems on the basis of modularization, including the dimensions of technology, organization and staff, which will enable industrial companies to make these complex socio-technical systems manageable.

Keywords: production system; socio-technical system; flexibility; changeability; modularization

1. Problem situation and motivation

In the global competition, industrial companies are exposed to an increasingly dynamic and turbulent market. Today they are confronted with an unpredictable as well as instable market situation [1]. In addition to unpredictable influences, e.g. the financial and economic crisis, the progressive globalization, the limitation of resources accessibility, unscheduled order fluctuations and the individualization of customer preferences have an impact on these companies [2, 3]. The constantly alternating requirements for industrial companies implicate the challenge to further develop production systems [4, 5]. In the field of production management, you can observe a paradigm shift from a flexible production to a changeable company [5]. A variety of already known drivers of change, e.g. new developments in technologies, have an impact on the production systems of industrial companies. This impact is irrespective of the sector, size and position in the value-added chain. In this context, the term production system can be understood as a socio-technical system which generates an input into an output with the aim of value-added and associated processes. These processes are created by technical and human resources [3]. Based on drivers of change, a demand of change is activated. This demand is noticed by companies but is not measureable in its direction and degree of strength [6].

Examples of external influences are the market, the environment and the economy as well as social and political factors. Internal factors arise inside the company, e.g. by the staff, new methods or products [7]. The outcome of this is a continuous (e.g. fluctuations in demand) or discontinuous (e.g. jumps in innovation) demand for change (Fig. 1). To face the resulting challenges, every enterprise has to define technically and organizationally realizable as well as cost-effective actions in an appropriate time [6]. One chance to react to changing requirements is to apply the principle of

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modularization [3]. In literature, modularity is referred to as one of the five change enablers and thus has a wide influence on the changeability of production systems [4]. By the term modularity, concepts are integrated which aspire the reduction of complexity by creating smaller units [3, 8]. In literature as well as in practice, there are already existing miscellaneous approaches for a modular design of factory and production systems. But conventionally, modularization is considered in a technical context. The connections to staff and organization are disregarded as far as possible [3]. For the modular design of holistically changeable production systems, the consideration of the dimensions of technology, organization and staff as well as the analysis of the correlations between them is essential [6].

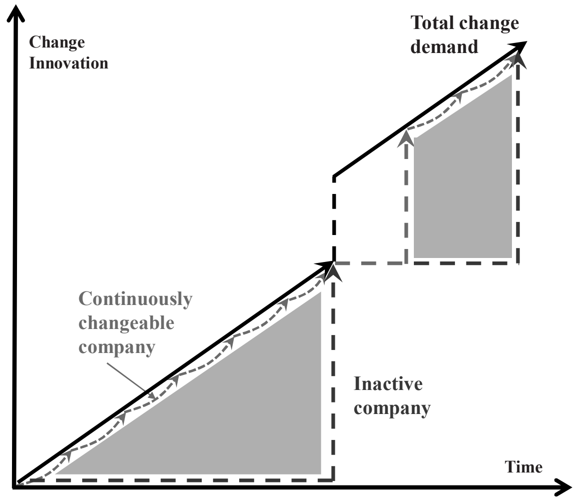

Fig. 1. Complete demand of change [11]

2. Factor of success: changeability

For quite some time, changeability has been perceived as an essential factor of success for the sustainable factory [4]. Changeability marks the acquirement of a complete factory to adapt itself to changing requirements in a reactive or proactive way [9]. Based on this understanding, changeability can be defined in the following way: “Changeability characterizes the potential of a factory to realize a target-oriented new- and re-configuration in a reactive or proactive way, by the use of system- and structure-immanent enablers, with the aim to raise or maintain the internal and external efficiency of the factory” [10]. In contrast to flexibility, changeability is perceived as a potential to perform necessary changes outside predefined corridors (Fig. 2). These corridors can be shifted vertically as well as customized in their horizontal width. Compared to flexibility, the range of capability will not be provided but pre-thought for possible changes [3].

Reinhart et al. does not consider changeability as an extension of flexibility, but rather as an element. Changeability consists of flexibility and reactivity and is described as a “dimension of company capability to adapt on a turbulent environment” [14].

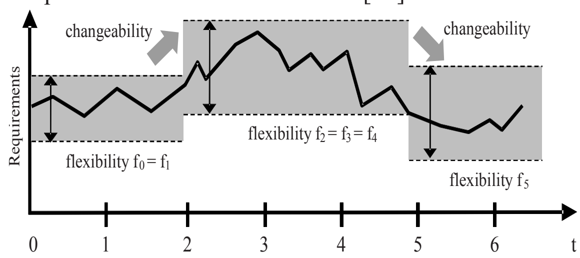

Fig. 2. Differentiation of flexibility and changeability [3]

3. Research project WamoPro – a holistic approach

The first step of the research project is to analyze the considered production system regarding change-affecting factors. The second step includes a company-specific partition into modules of the dimensions of technology, organization and staff. An extension of new modules as well as an optimization and substitution of existing modules may result from modularization and synchronization. In a further step of the project, modularly designed production systems will be configured and incorporated into the overall system of the company. In this process, interfaces to other sectors need to be implicated. Furthermore, the research project focuses on the design of a cost-benefit benchmark tool for sustainable changeability and a structured as well as standardized compilation of developed methods and tools. By the use of this compilation, the sustainability and the control of the configuration will be guaranteed [11].

This paper predominantly considers a novel modular design approach and disregards the topics of cost-benefit analysis, self-assessment and early-warning.

4. Design of changeable production systems

The fast and efficient adaption of production systems is essential for reacting to exterior turbulences and the resulting demands for change. In the context of the research project “WamoPro”, production systems are considered as an interrelation between modules of the dimensions of technology, organization and staff (Fig. 3). The below introduced approach for a modular design of production systems considers this interrelation and is based on the application of the principles of modeling. Models are earmarked copies of the reality, which concentrate on elements that are relevant for a specific issue [12]. These days, modeling is an evidence for the presumption of a future reality and considered as an approach for an active design of systems [13]. The principle of systems has a significant role for the below introduced concept. According to the definition of the general systems theory, a system consists of a lot of elements with attributes, which are combined by relations [15]. This approach allows for the development of changeability as an attribute [10] and an easier handling of the complex processes within a factory and/or a production systems, respectively [4].

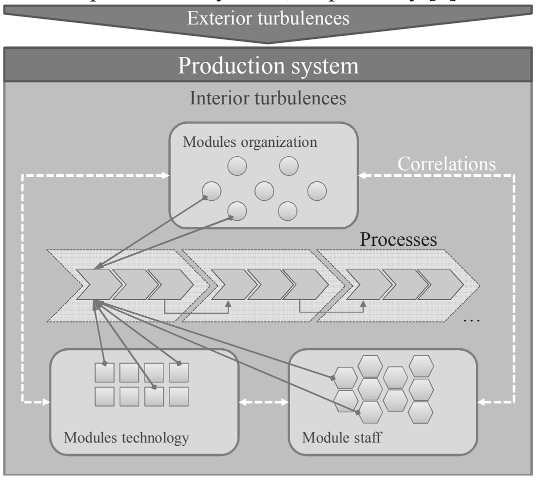

Fig. 3. Interrelation between technology, organization and staff [3]

4.1. Modularization of production systems

Considering a complete company, it is first necessary to transmit it into a company-specific hierarchy-level model in order to realize a methodical and company-specific modularization. The developed approach pursues the goal to design a module library depending on hierarchy levels. By the use of this library, a designer of change, usually the head of the considered sector, is enabled to react to demands of change. Because of this purpose, an aggregation of modules from the lowest to the highest hierarchy level is not compulsory. The developed module library is adapted to the specific requirements and options for action of the designer of change. It contains all necessary modules for a new- or re-design of the modularized sector. Furthermore, the approach leads to a redundant deposit of modules in various levels and sectors. After an explicit determination of a designer of change and the associated sector of designing, the "modularization analysis" is executed in two steps. The first step is the "stock analysis" based on a description and analysis of relevant business processes, e.g. development, distribution and so on. The second step is the analysis of sphere activities. Inside this step, processes are generated and analyzed on the basis of scenarios. These scenarios result from the identification of change-affecting factors on the considered company sector. An appropriate method for this has already been developed within the project [16] but will not be introduced in this article. The analysis of sphere activities is used for the identification of additional and/or substituted modules. These modules need to be available for possible demands of change and form a pre-thought solution space.

In the following, the single process steps (activities) are considered in detail. This detailed consideration contains the identification of modules which are required for the realization of activities and a detailed description of the identified modules. For this purpose, modules will not only be allocated to a dimension of change but also to an element of change [17]. Beside this allocation to an element of change, relevant attributes are deposited in every module. With a view to the configuration approach which will be introduced below, the structure of organizational modules of the element "method" deviate from the other modules. To control the configuration procedure on the basis of referential processes, it is necessary that these modules have the form of a process-describing method.

All identified modules including their attributes will be archived in a level- and/or sector-specific module library, respectively.

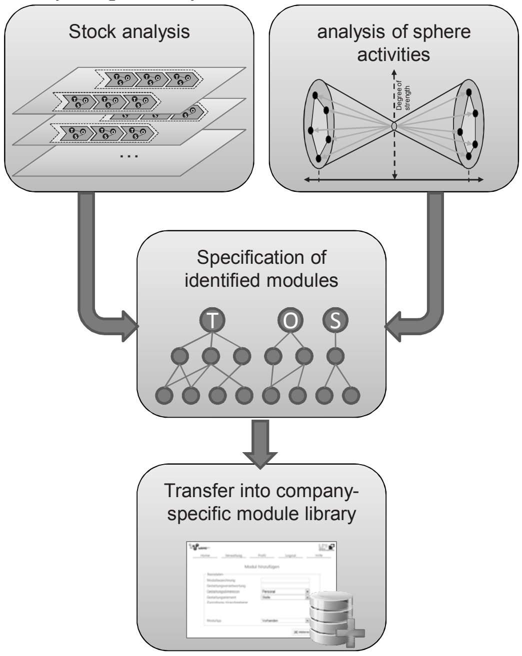

Fig. 4. Procedure of modularization

4.2. Approach for configuration

For the design of changeable production systems, a systematical identification and archiving alone is insufficient but tools are also needed to describe the correlations between the single modules. The below introduced approach considers the correlations between the company-specific modules and enables a systematic configuration of production systems by the use of defined norms of modeling. Hereby, a system based on connected elements with a dynamic system boundary occurs. This system boundary results from the integration and the attributes of the used elements.

In the preparation of the development of the approach for configuration, relevant requirements have been defined such as:

- a standardized graphical display format
- consistent imagery for the design dimensions and connecting elements
- structured and defined modeling rules
- a systematic alignment of requirements and attributes of the modules
- universal practicability
- the possibility to design alternative configuration solutions
- expandability with regard to a software tool

Especially the systematic alignment of requirements and attributes plays an essential role in the development as well as the future application of the method. By the use of the modularization approach and the associated archiving of all identified modules including their relevant attributes, the necessary requirements and attributes of each module are defined. The alignment of requirements and attributes occurs by the principle of acting and reacting modules. The inspection of the fulfilling of all requirements results from an alignment of the requirements of the acting module with the attributes of the reacting module. In case of the fulfillment of all requirements a feedback of secondary requirements (requirements of the reacting module) occurs (Fig. 5). When an appropriate module (concordance of requirements and attributes) is identified, it is added to the system.

For the modeling of the configuration solutions, a graphical display format has been developed that consists of symbols for the three dimensions of change and the connecting edges. Because of the enormous complexity of configuration solutions and the associated bustle by the modeling, three types of edges are differed in this approach:

- Directed (interrupted) edges connect an organizational module and a newly added module as long as the requirements of this have not been completely fulfilled. Hereby, the requirements of the new module will be regenerated to the organizational module.
- Non-directed (interrupted) edges exist between organizational modules as long as all requirements of the subordinated modules are unfulfilled.
- Non-directed (continuous) edges result from directed (interrupted) or non-directed (interrupted) edges as soon as the complete requirements of the corresponding module are fulfilled.

The initial point of every configuration is formed by organizational modules of the design-element “method” that are related to activities. These activities result from the “stock analysis” as well as the analysis of sphere activities and are available for the designer of change to react to demands of change.

The single requirements of the configuration-controlling module will be executed within the configuration procedure step by step. Fig. 5 illustrates the algorithm of the configuration procedure.

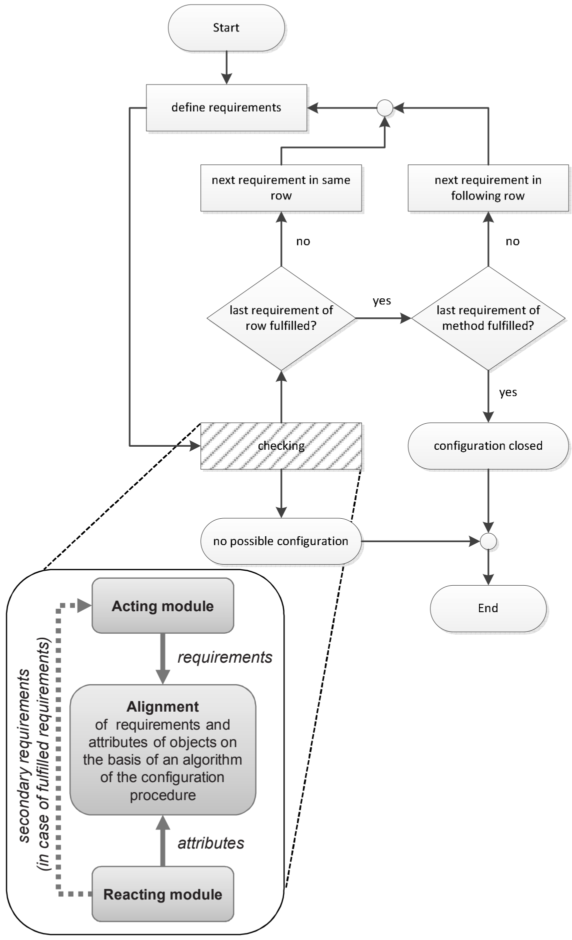

Fig. 5. Algorithm of the configuration procedure

Associated to the structure of an organizational module of the specification “method” introduced in chapter 4.1, all requirements of a row (horizontal execution of the method) will be considered before a transition to the next row occurs. When an appropriate module (concordance of requirements and attributes) is identified, it is added to the system. If there are several modules which fulfill the requirements, alternative solutions will be generated. These solutions are represented in independent systems whereby parallel paths of development emerge. In the next step, the connected module links its specific requirements to the dedicated organizational module. This module is then expanded by the requirements of the connected module. In the following configuration process, all further requirements are aligned with the modules that are already existing in the system. This step has the aim to reduce the complexity of developed systems and to create the minimum number of module connections.

Because of the feedback of requirements (Fig. 5), organizational modules of the design-element “method” have an essential role. They control the procedure of configuration. By each connection, the requirements of the module and, according to this, the complexity of the whole system expands. To realize the dynamic system configuration, two types of requirements of the design-element “method” are differentiated. On the one hand, there are primary requirements that hail from the original module. On the other hand there are secondary requirements that result from the connections to other modules. In the case of a connection with further organizational module of the design-element “method”, there is no feedback between these modules. In this connection, an equivalent process occurs.

If there are no more appropriate modules which can be identified in the course of the configuration procedure, the developed alternative will be abolished and another alternative will be chosen. Normally, at the end of each configuration, several alternatives are generated that have to be checked by cost-benefit aspects. In the project “WamoPro”, a tool for a cost-benefit analysis will be developed but will not be considered within this article.

5. Practical application of the approach

In the following, the concepts of modularization and configuration are illustrated on the basis of a practical example which has been developed within the research project “WamoPro”. In the first instance, the two steps (“stock analysis” and “analysis of sphere activities”) of the “modularization analysis” have been executed on the basis of the considered company. For this purpose, several company-specific processes have been recorded and analysed with the aim to identify corresponding modules. Fig. 6 represents an exemplary result of the analysis of sphere activities.

By the use of this process analysis, existing as well as invented modules of the dimensions of technology, organization and staff have been identified and archived in a level- and/or sector-specific module library.

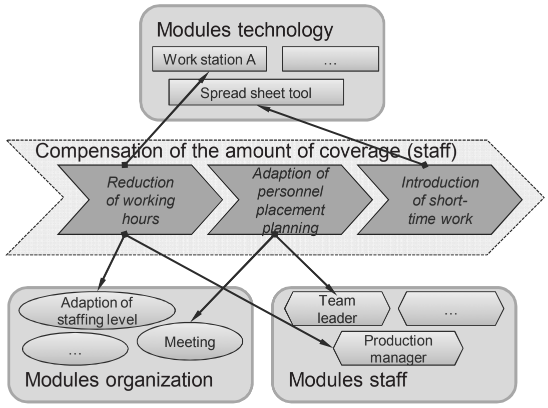

Fig. 6. Example of an analyzed process

On the basis of this module library and by the use of the approach for configuration, the designer of change has been enabled to model complex but realistic configuration solutions very quickly. An example for a designed configuration solution within the project is illustrated in Fig. 7.

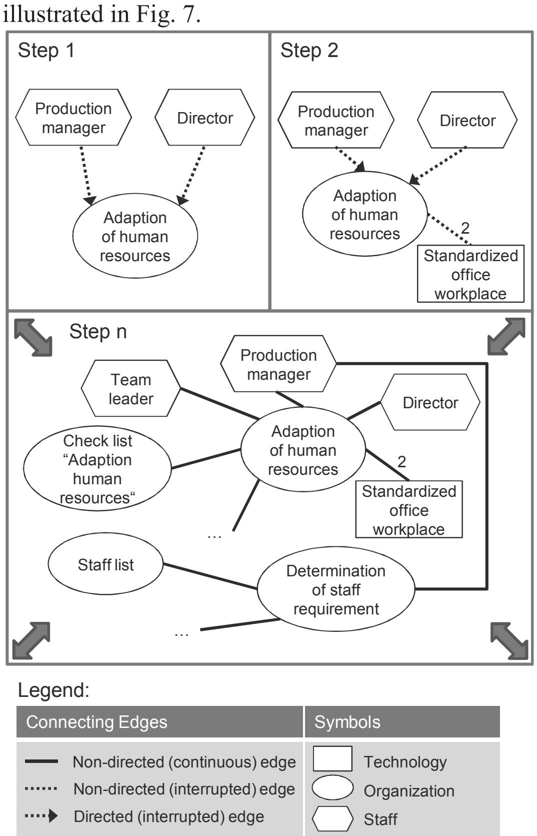

Fig. 7. Exemplary configuration solution

6. Summary

This article introduces a concept for a modular design of production systems that enables a structured identification and consideration of modules for a specific company sector. In the face of a new- or re-configuration of the considered sector, the correlations between the various modules have an essential relevance. These correlations are already considered at the process of modularization with the aim to enable a configuration of changeable production systems at all.

The approach for configuration also introduced in this paper includes a methodical procedure and designing rules that enable the configuration of production systems based on the results of modularization.

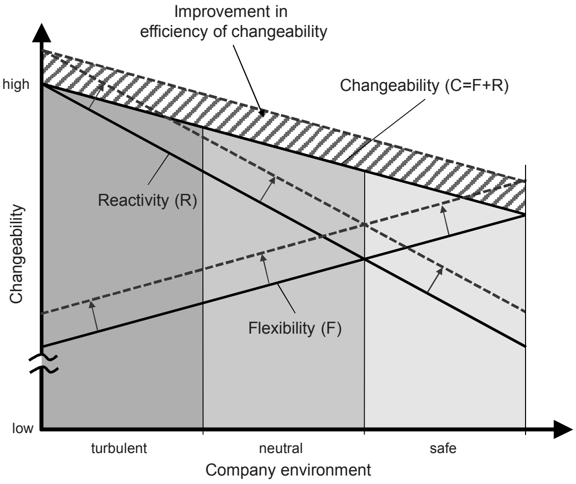

Fig. 8. Improvement of changeability [14]

The above introduced methodical approaches of modularization and configuration have been proved and validated by several industrial enterprises in the context of the cooperative project “WamoPro”. The implementation in the industrial sector has demonstrated, that the approaches allow a systematical control of predictable and projectable scenarios (improvement of flexibility). Furthermore, potentials for action are constituted which can be directly activated in case of need (improvement of reactivity). Considering the definition of changeability appropriate to REINHART et al. [14], the use of the introduced approaches will finally cause an improvement of changeability (Fig. 8).

Because of the design of a cost-benefit-tool, the central idea of sustainable changeability will be considered at all times. By a practically oriented aggregation of the developed and validated methods as well as tools, the sustainability of changeability can be guaranteed.

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